Influence of Edge Preparation on the Performance of Coated Cutting Tools

Invited talk of T. Cselle
International Conference on Metallurgical Coatings and Thin Films
San Diego, 2nd of May, 2007
Influence of Edge Preparation on the Performance of Coated Cutting Tools

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Influence of Edge Preparation on the Performance of Coated Cutting Tools

Invited talk of T. Cselle at ICMCTF, San Diego, 2nd of May, 2007

APPLICATIONS
- Drilling
- Milling
- Turning
- Tapping
- Sawing

WHY EDGE PREPARATION?
- Form
- Surface
- Cutting material

TREATMENTS
- Grinding
- Brushing
- Micro Blasting
  - Dry
  - Wet
- Drag Grinding
- Magnet Finishing

Goal of edge preparation: increase

↑ CUTTING PERFORMANCE ↑
Influence of Edge Preparation on the Performance of Coated Tools

The AIM of Edge Preparation:

1. Directly on sharp edge the PVD coating has a very high internal stress.
2. Because of this very high internal stress the coating breaks away, peels off very shortly after starting cutting.
3. The tool's wear is always measured on the surface of the cutting material where the coating isn't present anymore.
4. The goodness, the quality of a coating is strongly determined by the ABILITY of the coating TO KEEP THE GROWTH OF DISTANCES $CPoR$ and $CPoC$ SLOW during the cutting process, along the tool life.
   - $CPoR$: coating's peeling off on the tool's rake surface
   - $CPoC$: coating's peeling off on the tool's clearance surface
5. The aim of a good edge preparation is:
   - to "ensharp" the cutting edges
   - to make a smooth transition of the coating possible between the tool's rake and clearance surfaces and with this
   - to reduce the internal stress of the coating
   - but without making the tool blunt

Coating's peeling off and tool wear on the end mill with edge preparation "A" after 40 m cutting distance

Coating's peeling off and tool wear on the end mill with edge preparation "B" after 40 m cutting distance
WHY Edge Preparation?

Target: EDGE STABILITY
- Form:
  - (low) chipping

Tool Edge Images from High End Tool Manufacturers after Grinding

End Mill Corner:

After grinding

After edge preparation
WHY Edge Preparation?

Target: EDGE PREPARATION
- Form:
  - (low) chipping
- Surface:
  - (low) roughness

Tool Edge Images from High End Tool Manufacturers after Grinding

Carbide Drill:
WHY Edge Preparation?

Target: EDGE PREPARATION
- Form:
  - (low) chipping
- Surface:
  - (low) roughness
- Cutting Material:
  - (correct) composition

WHY Edge Preparation?

Rockwell adhesion test

Tool Surface Images from High End Tool Manufacturers

Carbide Drill:
- Coating on cobalt leached surface
  - coating on WC layer without/with few binder (cobalt)
  - very bad adhesion

500x
Cobalt leaching
Influence of Corner Edge Preparation on the Performance of Coated Drills

APPLICATION 1

- Drilling
- Milling
- Turning
- Tapping
- Sawing

Target: EDGE STABILITY

- Form
- Surface
- Metallurgy

TREATMENTS

- Grinding
- Brushing
- Micro blasting
  - Dry
  - Wet
- Drag grinding
- Magnet finishing

Work piece material: cold working steel - 1.2379 - X155CrVMo12-1 – HRC22 - blind holes
Solid carbide drills with nACo coating: d=5 mm, vc=75 mm/min – fz=0.15 mm/z – ap=15 mm – dry air coolant
Influence of Corner Edge Preparation on the Performance of Coated Drills

Work piece material: cold working steel - 1.2379 - X155CrVMo12-1 – HRC22 - blind holes
Solid carbide drills with nACo coating: \( d = 5 \text{ mm}, v_c = 75 \text{ mm/min} \) – \( f_z = 0.15 \text{ mm/z} \) – \( a_p = 15 \text{ mm} \) – dry air coolant

- Rounded edges without corner honing
- Rounded edges with corner honing
Influence of Corner Edge Preparation on the Performance of Drills

- as ground R = 3 µm
- R1 = 11 µm
- R2 = 15 µm
- R3 = 21 µm

Drilling distance [m]

Corner wear [µm]

- edge sharp as ground
- edge rounded without edge honing R=15 µm
- edge with honing without rounding
- edge with honing and rounding R=15 µm

Influence of Corner Edge Preparation on the Performance of Drills

Edge brushing of inclined driven tools

- T1 = 1 min
- T2 = 2 min
- T3 = 3 min

as ground R = 3 µm
- R1 = 11 µm
- R2 = 15 µm
- R3 = 21 µm
### Influence of Edge Preparation on the Performance of Coated End Mills

**APPLICATION 2**

- Drilling
- Milling
- Turning
- Tapping
- Sawing

**Target:** EDGE STABILITY

- Form
- Surface
- Cutting material

**TREATMENTS**

- Grinding
- Brushing
- Micro blasting
  - Dry
  - Wet
- Drag grinding
- Magnet finishing

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**Influence of the Edge Preparation on Tool Life at Standard End Mills in Easy to Cut HEAT TREATED Steel**

Material: 1.7225 – 42CrMo4 – 4140H – coolant; dry air

End mill: AlTiN coated - d=10mm, z=4, ae=1 mm – ap=nd – vc=140 m/min – fz=0.1 mm/z
Influence of Edge Preparation on the Performance of Coated End Mills

No tool life difference for different coatings because of instable chattering during milling process.

Max. Wear is always at the corner as chipping, break out.

Work piece material: cold working steel - 1.2312 - 40CrMnMo8-6 – heat treated - Rm=1000 N/mm² - HRC32
HM end mills: d=12mm - z=4 - vc=200 mm/min – fz=0.1 mm/z – ae=ap=6mm – down cut– coolant: dry air 6 bar
Influence of Edge Preparation on the Performance of Coated End Mills

The sharp, weak edge causes chatter
The honed, stable edge reduces chatter

Influence of Edge Preparation on the Performance of Coated End Mills

The edge bevel increases tool life by 80%

Work piece material: cold working steel - 1.2312 - 40CrMnMoS8-6 – heat treated - Rm=1000 N/mm² - HRC32
HM end mills: d=12mm - z=4 - vc=200 mm/min – fz=0.1 mm/z – ae=ap=6mm – down cut– coolant: dry air 6 bar
Influence of the Edge Preparation on Margin Wear after $L_m=60$m at Standard End Mill in HEAT TREATED Steel

-Honing = 0 um
-Honing = 10 um
-Honing = 15 um
-Honing = 20 um
-Honing = 30 um
-Honing = 40 um

Material: 1.7225 – 42CrMo4 – 4140H – coolant; dry air
End mill: AlTiN coated - $d=10$mm, $z=4$, $a_e=1$ mm – $ap=0.5$d – $vc=140$m/min – $f_z=0.1$ mm/z
Edge Preparation for High Performance Torus End Mill

After grinding

After edge prep

Influence of the Edge Preparation on Tool Life at High Performance Torus End Mill in HIGH ALLOYED Steel

Material: 1.2379 - X155CrVMo12-1
End mill: nACRo coated - d=10mm, z=4, ae=0.25 x d – ap=1.5 x d – vc=150 m/min – fz=0.05 mm/z
Influence of Edge Preparation on the Performance of Coated Cutting Tools

Edge Preparation after Coating

- The edges are rounded after coating
- The coating is moved away around the edge
- The edge is "set free"

Advantages of edge preparation after coating:
- Edge rounding &
- Droplet removing in one step

Disadvantages of Edge Preparation after Coating:
- Interruption of coating structure on long surface line
- Full and direct contact of cutting and work piece material immediately
- Lower heat and chemical insulation
- Low coating thickness near to the edge
- Full coating structure begins far away from cutting edge
- Bigger edge radius (e.g. for roughing) results larger surfaces without coating
- Impression of bad coating
Influence of Edge Preparation on the Performance of Coated Inserts

APPLICATION 3
- Drilling
- Milling
- Inserts for
  • Turning
- Tapping
- Sawing

Target: EDGE STABILITY
- Form
- Surface
- Cutting material

TREATMENTS
- Grinding
- Brushing
- Micro Blasting
  – Dry
  – Wet
- Drag Grinding
- Magnet Finishing

Turning inserts from the production:
- top: sintered (Co-riched)
- side: ground (Co-leached)
- blasting is a MUST!
How Much Cobalt Leaching Can Be Accepted?

WHY Cobalt Leaching?
- grinding with critical emulsion coolant
- grinding at too high parameters
- grinding with blunt grinding wheels
- non correct stripping

Cobalt leaching

Rockwell adhesion test

Coating on cobalt leached surface
- coating on WC layer without/with few binder (cobalt)
  - very bad adhesion

Evaluation by the Rockwell test from Mercedes Benz:
Characterization the goodness of coating adhesion by HF classes

Good adhesion:
- HF1
- HF2
- HF3

Deviant adhesion:
- HF4

Bad adhesion:
- HF5
- HF6

TEST PARAMETERS
- Substrate Hardness: 54 HRE minimum
- Coating Thickness: 30 µm maximum
- Indentation: Rockwell C
- Visual Magnification: 100x
How Much Cobalt Leaching Can Be Accepted?

For good coating adhesion on K30/40 carbide with 10% cobalt

For good coating adhesion on K10 carbide with 6% cobalt

Limit for good adhesion:
- K30/40 carbide with 10% cobalt: 1%
- K10 carbide with 6% cobalt: 0.7%
How to Check Cobalt-Leaching on Carbide?

Rubber Test on Carbide

Check the carbide surface under 100x magnification

Cobalt-Leaching showed by rubbing on K40 carbide with 10% Cobalt

No Co-Leaching

Acceptable Co-Leaching 0.3%

Co-Leaching in the limit 1%

Co-Leaching over the limit 2.2%
Improvement of the Surface Density and Coatability by Micro Blasting

Tool surface with cobalt-leaching  Tool surface after micro blasting
Without cobalt-leaching

Measuring Cobalt Leaching by X-Ray

Focusing on the margin of the tool  Spectrum with Co and W
Improvement of the Surface Density and Coatability by Micro Blasting

Dry or Wet by Micro Blasting?
Comparison of Achievable Surface Structure

<table>
<thead>
<tr>
<th></th>
<th>Ground carbide</th>
<th>Dry</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDX [wt-%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5.1</td>
<td>6.7</td>
<td>5.4</td>
</tr>
<tr>
<td>O</td>
<td>0</td>
<td>4.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Co</td>
<td>8.6</td>
<td>7.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Cr</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>W</td>
<td>85.9</td>
<td>82.1</td>
<td>85.1</td>
</tr>
</tbody>
</table>

Ground carbide before blasting

Dry

Wet
Improvement of the Surface Density and Coatability by Micro Blasting

Dry or Wet by Micro Blasting?
Comparison of Achievable Surface Roughness (AFM)

<table>
<thead>
<tr>
<th>Surface roughness</th>
<th>DRY</th>
<th>WET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa=0.11 um</td>
<td></td>
<td>Sa=0.05 um</td>
</tr>
<tr>
<td>Sz=1.14 um</td>
<td></td>
<td>Sz=0.32 um</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rest material after blasting</th>
<th>DRY</th>
<th>WET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smearing of residual material</td>
<td></td>
<td>Danger of cobalt leaching because of water</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coating adhesion</th>
<th>DRY</th>
<th>WET</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF1</td>
<td></td>
<td>HF1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Edge rounding</th>
<th>DRY</th>
<th>WET</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Filling&quot; required</td>
<td></td>
<td>Better to control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main features</th>
<th>DRY</th>
<th>WET</th>
</tr>
</thead>
<tbody>
<tr>
<td>- No drying needed after blasting</td>
<td></td>
<td>- Drying after blasting needed</td>
</tr>
<tr>
<td>- Easy handling at interrupted work</td>
<td></td>
<td>- Difficult cleaning at interrupted work</td>
</tr>
<tr>
<td>- Lower price</td>
<td></td>
<td>- Higher price</td>
</tr>
</tbody>
</table>
Influence of Edge Preparation on the Performance of Coated Inserts

Drag Finishing in Polishing Machine by Special Powder

with 2 driven axes

with 3 driven axes

Influence of Edge Preparation on the Performance of Coated Inserts
Influence of Edge Preparation on the Performance of Coated Inserts

Before blasting with Alox and polishing by drag finishing

Work piece material: sintered PM steel - Rm=1000 N/mm² – Insert: CPGT 05T104 FN20 DS10
vc=250 mm/min – f=0.11-0.13 mm/rev – ap=0.6mm – Source: Deni, Switzerland
Influence of Prepared Edge Shape on the Performance of Coated Inserts

Source: iwf University Hannover, Germany - Material: carbon steel - Ck45N - dry
HM insert: SNGA 120408 – KMF – TiAlN – vc=200 m/min – f=0.25mm/rev – ap=1.5mm
Influence of Edge Preparation on the Performance of Coated Taps

APPLICATION 4

- Milling
- Drilling
- Turning
- Tapping
- Sawing

Target: EDGE STABILITY

- Form
- Surface
- Metallurgy

TREATMENTS

- Grinding
- Brushing
- Micro Blasting
  - Dry
  - Wet
- Drag Grinding
- Magnet Finishing

Influence of Edge Preparation on the Performance of Coated Taps

Without polishing

After polishing
Edge Preparation with Magnetic Powder with Robot Manipulation for Large Scale Tool Production

Edge Preparation of Small Tools (d>1mm) with Magnetic Powder Head as a "Grinding Wheel"

Source: MF & Schütte
Influence of Edge Preparation on the Performance of Coated Taps

Magnification: 100x

Before polishing

After polishing

Work piece Material: carbon steel - C45K – Coolant: emulsion 7%
Tools: rigid taps - M3 – a=1.5xd – blind holes - vc=10 m/min
Influence of Edge Preparation on the Performance of Coated at Wood Cutting

APPLICATION 5

- Drilling
- Milling
- Turning
- Tapping
- Sawing

Target: EDGE STABILITY

- Form
- Surface
- Metallurgy

TREATMENTS

- Grinding
- Brushing
- Micro Blasting
  - Dry
  - Wet
- Drag Grinding
- Magnet Finishing

Influence of Edge Preparation on the Performance of Coated at Wood Cutting

Expert's opinion:
The Cutting Edge Must Be Sharp! ?

Therefore coating hardly used in wood cutting:

Only 2% wood cutting tools are coated!
Influence of Edge Preparation on the Performance of Coated at Wood Cutting

Expert's opinion:
The Cutting Edge Must Be Sharp! ?

Therefore coating hardly used in wood cutting; Only 2% wood cutting tools are coated!

When coated the edge will be resharpened immediately after coating Performance increase is not impressing!

Full coating after very fine edge rounding increases tool performance significantly even for WOOD CUTTERS
Influence of Edge Preparation on the Performance of Coated Cutting Tools

Summary: Comparison of Treatment's Features

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Typical time / shank tool</th>
<th>Flexibility</th>
<th>Costs / Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brushing</td>
<td>2 min / 6 = 20 sec</td>
<td>good</td>
<td>medium</td>
</tr>
<tr>
<td>Drag grinding</td>
<td>12 min / 24 = 30 sec</td>
<td>medium</td>
<td>medium to high</td>
</tr>
<tr>
<td>Dry blasting</td>
<td>20 sec</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>Wet blasting</td>
<td>10 sec.</td>
<td>medium to high</td>
<td>low</td>
</tr>
<tr>
<td>Magnet finishing</td>
<td>20 sec</td>
<td>medium</td>
<td>medium to high</td>
</tr>
</tbody>
</table>

Influence of Edge Preparation on the Performance of Coated Cutting Tools

Edge Treatment Methods

<table>
<thead>
<tr>
<th>Criteria / Features</th>
<th>Honing by Hand (with abrasive lathes)</th>
<th>Brushing</th>
<th>Drag-Grinding (Polishing)</th>
<th>Micro Honing Dry</th>
<th>Micro Honing Wet</th>
<th>Water Beam</th>
<th>Magnet Finishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Conformity</td>
<td>high</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
<td>medium</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Flexibility</td>
<td>very high</td>
<td>good</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>Productivity</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>Price</td>
<td>high</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Standard machines available</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Polishing possible</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Drying possible</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Additional features</td>
<td>typical for small diameters</td>
<td>effective for small diameters</td>
<td>no additional cost on the surface</td>
<td>easy to handle</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Influence of Edge Preparation on the Performance of Coated Cutting Tools

Summary

- Without edge preparation
  - low performance

- Different work piece materials to be cut
  - need different edge preparation

- Over the optimum edge preparation
  - performance drops down abruptly

- Optimum edge preparation
  - increases performance enormously

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F. Barthelme, P. Preiss, S. Reich, GFE, Schmalkalden, Germany, M. Ruzicka, PIVOT, M. Sima, SHM, Sumperk, Czech Republic
T. Cselle, PLATIT, Grenchen, Switzerland
The “2005 Excellent Product Design Award” was awarded to PLATIT and PIVOT for the design of the p80 and p300 coating units and associated peripherals.